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PROCEEDINGS

OF

THE ROYAL IRISH ACADEMY.

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MONDAY, NOVEMBER 11, 1861.

VERY REV. DEAN GRAVES, D.D., President, in the Chair.

The REV. HUMPHREY LLOYD, D.D., read the following paper :—

ON EARTH CURRENTS, AND THEIR CONNEXION WITH THE PHENOMENA OF TERRESTRIAL MAGNETISM.

(Plate I.)

IN the year 1848, Mr. Barlow communicated to the Royal Society a Paper "On the Spontaneous Electrical Currents observed in the Wires of the Electric Telegraph," in which he established the important fact that a wire, whose extremities are connected with the earth at two distant points, is unceasingly traversed by electric currents, the intensity of which varies with the azimuth of the line joining the points of contact with the ground. The direction of these currents was proved to be the same at both extremities of the same wire, and was shown to depend on the relative positions of the earth-connexions, while it was wholly independent of the course followed by the wire itself. The currents cease altogether when either of the contacts with the earth is interrupted. From these facts Mr. Barlow concluded, that "the currents are terrestrial, of which a portion is conveyed along the wire, and rendered visible by the multiplying action of the coil of the galvanometer."

Mr. Barlow further observed, that apart from the sudden and occasional changes, the general direction of the needle of the galvanometer appeared to exhibit some regularity. He was thus led to institute a series of observations for fourteen days and nights, on two wires simultaneously, one from Derby to Rugby, and the other from Derby to Birmingham, the positions of the needles in both circuits being recorded every five minutes, day and night. From these observations he concluded—

"1. That the path described by the needle consisted of a regular diurnal motion, subject to disturbances of greater or less magnitude.

"2. That this motion is due to electric currents passing from the northern to the southern extremities of the telegraph wires, and returning in the opposite direction.

"3. That, exclusive of the irregular disturbances, the currents flowed in a southerly direction from about 8 or 9 A.M. until the evening, and in a northerly direction during the remainder of the twenty-four hours."

He was thus led to examine whether any relation subsisted between these movements and the daily changes of the horizontal magnetic needle; and having made, for this purpose, a series of simultaneous observations with a delicate declinometer, he came to the conclusion that although, generally, the currents flow *southwards* during that part of the day in which the variation of the horizontal needle is *westerly* (i. e. from 8 or 9 A.M. until the evening), and *northwards*, when the variation is *easterly* (i. e. during the night and early part of the morning), "yet simultaneous observations showed no similarity in the path described by the magnetic needle and the galvanometer."

An examination of Mr. Barlow's galvanometric observations led me, some time since, to an opposite conclusion; and at the last meeting of the British Association, I stated my conviction, founded on these observations, that the earth-currents, whose continuous flow Mr. Barlow has the merit of establishing, would eventually explain all the changes of terrestrial magnetism, both periodic and irregular. I now proceed to state the grounds of this conviction, and to show, from Mr. Barlow's observations, that the diurnal changes of the earth currents correspond with those of the horizontal component of the earth's magnetic force.

Let us suppose, then, that the forces which act upon the horizontal needle, and which cause it to deviate from its mean position, are due to electric currents, traversing the upper strata of the earth in a horizontal direction; and let ξ denote the intensity of the current in the magnetic meridian, *positive* when flowing *northwards*, and *vice versâ;* and η the intensity of the current perpendicular to the magnetic meridian, *positive* when flowing *eastward*, and *vice versâ*. Then the force of the current in any direction, making the angle ϵ with the magnetic meridian (measured to the east of north) is

$$\phi = \xi \cos \epsilon + \eta \sin \epsilon.$$

Now ξ is proportional to the force which deflects the freely suspended horizontal needle from its mean position, or to $X\Delta\psi$, X being the horizontal component of the earth's magnetic force, and $\Delta\psi$ the change of declination expressed in parts of radius. Similarly, η is proportional to the force which deflects from its mean position a magnet, which is maintained (by torsion or other means) in a position perpendicular to the magnetic meridian; and is measured (in terms of X) by the relative changes of the horizontal intensity, taken negatively. Hence the force of the current in any given direction may be determined in terms of the same units.

Now

$$\epsilon = a - \psi,$$

in which a is the azimuth of the line connecting the two stations, measured from the true meridian eastward, and ψ the magnetic declination measured in the same direction. The observations of Sir James Ross, at Derby, give $\psi = -22^\circ\, 25'$; and we have for the line connecting Derby with Rugby,

$$a = -13^\circ\, 7', \quad a - \psi = +9^\circ\, 18';$$

and for the line joining Derby and Birmingham,

$$a = +33^\circ\, 27', \quad a - \psi = +55^\circ\, 52'.$$

The first column of the following Table contains the mean variation of the magnetic declination at the alternate hours, for the month of May, as deduced from four years' observation of that element at the Dublin Magnetic Observatory. The second contains the corresponding values of the changes of the horizontal intensity, in ten-thousandths of the whole intensity; and the third and fourth the calculated values of the deflecting forces, in the line perpendicular to that connecting the earth contacts at Derby and Rugby, and at Derby and Birmingham, respectively, and expressed in terms of the same units. These latter numbers are, by hypothesis, proportional to the intensities of the currents directed along the connecting wires.

TABLE I.—*Calculated Values of the Intensity of the Currents, traversing the Wires uniting Derby and Rugby, and Derby and Birmingham, respectively.*

Hour.	$\Delta\psi$	$\frac{\Delta X}{X}$	Derby and Rugby.	Derby and Birmingham.
1 A.M.	1′·8	0·4	5·1	2·6
3	2·5	− 1·6	7·6	5·5
5	3·9	− 3·7	11·9	9·5
7	5·2	− 8·4	16·2	15·4
9	2·1	− 16·9	8·9	17·5
11	− 4·1	− 15·9	− 9·3	6·4
1 P.M.	− 7·1	− 3·1	− 19·8	− 9·0
3	− 5·1	6·1	− 15·7	− 13·4
5	− 1·8	14·2	− 7·6	− 14·8
7	0·3	14·6	− 1·5	− 11·6
9	1·0	9·0	1·3	− 5·9
11	1·3	5·2	2·9	− 2·2

The galvanometric observations instituted by Mr. Barlow on these two lines were continued for fourteen consecutive days, commencing

May 17, 1848. Of these days of observation, however, six are incomplete, viz., May 17, 19, 20, 23, 24, 30; and another day (May 27) appears, from the Dublin observations, to have been a day of considerable magnetic disturbance. Omitting these, as unsuited to furnish true mean results, the means of the remaining days are as follow. The *positive* numbers indicate currents proceeding *towards* Derby, and the negative, currents in the contrary direction:—

Table II.—*Mean observed Values of the Intensity of the Currents, traversing the Wires uniting Derby and Rugby, and Derby and Birmingham, respectively.*

Hour.	Derby and Rugby.				Derby and Birmingham.			
	A. M.		P. M.		A. M.		P. M.	
1	- 1·4	0·3	- 5·0	- 5·1	0·2	1·5	- 9·1	- 8·5
2	2·5		- 5·5		2·9		- 7·7	
3	1·6	1·7	- 2·7	- 3·3	0·9	1·3	- 7·4	- 7·4
4	1·1		- 2·4		0·7		- 7·2	
5	0·5	1·2	- 1·8	- 2·3	0·6	1·2	- 3·6	- 5·1
6	2·7		- 3·2		2·8		- 6·3	
7	3·1	3·0	- 0·6	- 1·1	3·9	4·1	- 4·5	- 4·7
8	3·1		- 0·2		5·9		- 3·4	
9	2·4	1·8	0·4	0·2	4·2	3·4	- 0·8	- 1·7
10	- 0·9		0·1		- 0·6		- 1·7	
11	- 4·3	- 3·6	0·4	0·6	- 7·2	- 5·8	0·3	0·4
12	- 5·1		1·7		- 8·1		2·8	

It will be observed that the changes indicated by these numbers are very systematic. In the wire connecting Derby and Birmingham the current flows *southwards* from 10 A.M. to 10 P.M. inclusive, and *northwards* during the remaining hours. In the wire connecting Derby and Rugby, the *southward* current lasts from 10 A.M. to 8 P.M. inclusive, and it is *northward* (with a single exception) during the remaining hours. There are, however, as might be expected in so short a series, some irregularities in the course of the changes. In order to lessen these, and at the same time to confine the results to such as are comparable with the preceding, I have given (in the alternate columns of the Table) the means corresponding to the alternate hours, commencing at 1 A.M., computed by the formula

$$\tfrac{1}{4}(a + 2b + c).$$

The numbers so obtained are projected into curves in the diagram (Plate I.), having been previously multiplied by constant coefficients, in order to equalize the ranges with those of the computed results. The dotted lines, in both cases, are the corresponding projections of the calculated results. The agreement between these two sets of curves is probably as great as could be expected in the results of so short a series of observations; and we seem, therefore, entitled to conclude that the diurnal movements of the two horizontal magnetometers are accounted for by electric currents traversing the upper strata of the earth.

There is one point of difference, to which it important to draw attention. It will be seen that the *calculated* curves are, for the most part, *above the observed.* The reason of this will be evident upon a little consideration. The *zero* from which the calculated results are measured is the *mean of the day;* whereas that of the observed results is the *true zero,* corresponding to the absence of all current. Now, the chief deflections of the galvanometer needle (as appears from the latter curves) are those in which the sun is above the horizon; and the *zero line,* consequently, divides the area of the diurnal curve unequally, being considerably nearer to the night observations than to those of the day. If the calculated curves be displaced by a corresponding amount, their agreement with the observed will be much closer.

The difference here noted is one of considerable theoretical importance. Magnetometric observations furnish merely *differential* results, the magnitude and the sign of which have reference solely to an *arbitrary zero.* We are accordingly ignorant even of the relative values of the effects, and are unable to compare them with their physical causes, whether real or supposed. In these respects the galvanometric observations have the advantage. In them *positive* and *negative* are physically distinguished by the *direction* of the currents; and this, as well as the absence of all currents, is indicated by the instrument itself. The results, therefore, furnish the measures of the forces by which they are produced.

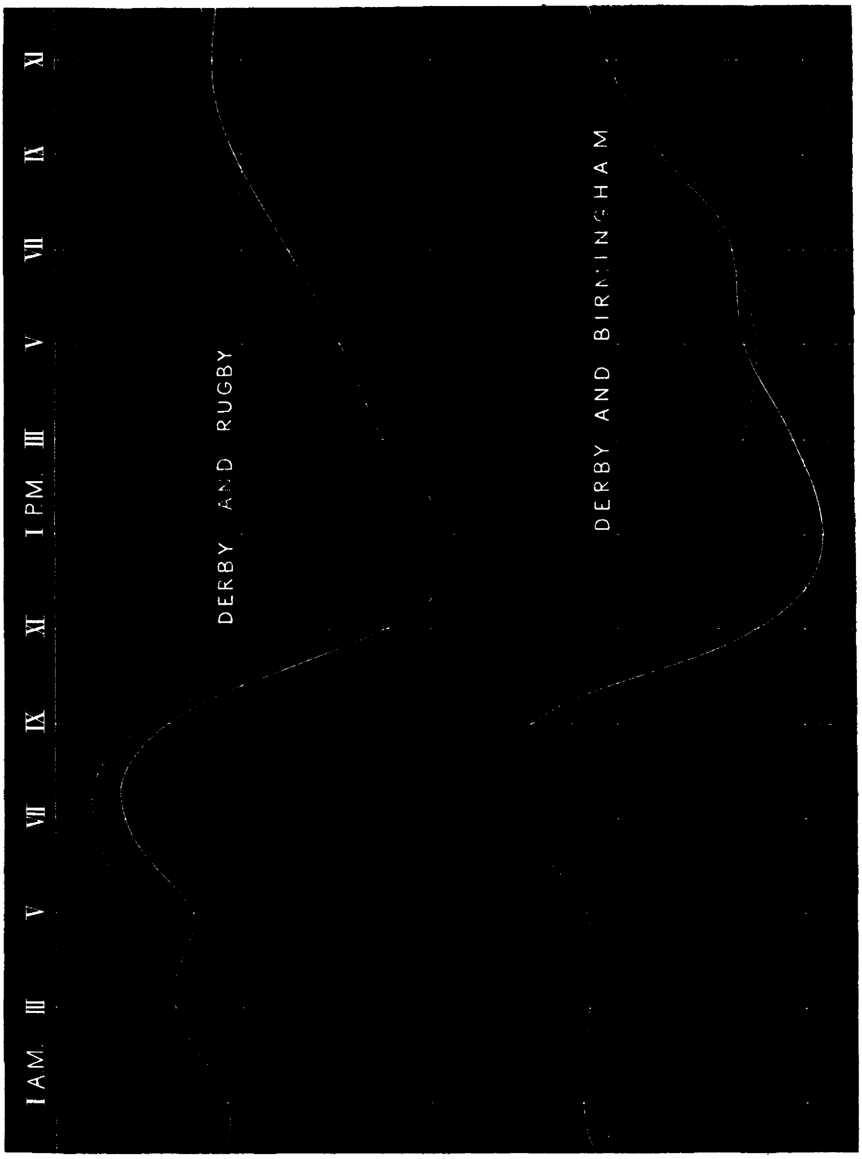
The next, and most important, step in this inquiry will be to assign the physical cause of these phenomena. The existence of electric currents traversing the earth's crust has hitherto been maintained as an *hypothesis,* on account of its supposed adequacy to explain the terrestrial magnetic changes. Now, however, their existence is proved, not only to be a *fact,* but also a fact sufficient to explain the phenomena. It remains, therefore, only to ascertain their source; and it will be for those who deny that the sun operates by its *heat* in producing the phenomena of terrestrial magnetism, to assign to these currents a more probable origin.

Professor William K. Sullivan read the following paper, written by himself and Joseph P. O'Reilly, C.E.:—

On the Hydrocarbonates and Silicates of Zinc of the Province of Santander, Spain.

GEOLOGICAL CONDITIONS UNDER WHICH THE ORES OF ZINC OCCUR.

The district of country comprised by the province of Santander lies between the prolongation of the Pyrenees, which, under various names, traverses the north of Spain, and the Bay of Biscay—the mountains forming



Graphical Comparison of the Numerical Results of Tables I. & II. of Dr. Lloyd's Paper on Earth Currents.

[The dotted line is the *calculated* Curve; the other the *observed* Curve.]